

"The Vapour Pressures of Liquid Oxygen on the Scale of the Constant-volume Oxygen Thermometer filled at different Initial Pressures." By MORRIS W. TRAVERS, D.Sc., Fellow of University College, London, and CHARLES J. FOX, B.Sc., Ph.D. Communicated by Sir WILLIAM RAMSAY, K.C.B., F.R.S. Received June 26, 1903.

The vapour pressures of liquid oxygen and liquid hydrogen on the scales of the constant-volume hydrogen and helium thermometers has recently been determined by one of us in conjunction with Dr. A. Jaquerod and Mr. G. Senter, and it has been found that two scales of temperature differ by amounts which increase as the temperature falls.

	Vapour pressure.	Hydrogen scale.	Helium scale.
Liquid oxygen .....	760 mm.	90°·10	90°·20
Liquid hydrogen .....	760	20°·22	20°·41

These results are in accordance with Callendar's calculations of the deviation from the thermo-dynamic scale of measurements with thermometers filled at an initial pressure of 1000 mm. of mercury at the melting point of ice. Whether the deviation becomes smaller when the thermometers are filled at a lower pressure has not been determined, and, indeed, with the means at our disposal it would be practically impossible to do so. In order, therefore, to investigate the variation of the readings of the gas thermometer with change of initial pressure, we decided to measure the vapour pressures of liquid oxygen on the scales of the constant-volume oxygen and nitrogen thermometers, for which the deviations from the thermo-dynamic scale are considerably greater.

*Previous investigations.*—The vapour pressure of liquid oxygen has been determined by Dewar,\* at temperatures near the boiling point, by means of a constant-volume oxygen thermometer. In calculating his results he employed the value 0·0036525 for the pressure coefficient of oxygen.

*The pressure coefficient of oxygen.*—Makower and Noble,† using the apparatus and method of Travers and Jaquerod, have determined the pressure coefficient of oxygen at pressures corresponding to 375 and 700 mm. of mercury. Their results lead to the conclusion that the coefficient increases with rise of pressure, and if the variation can be

\* 'Roy. Soc. Proc.,' 1901, vol. 68, p. 44.

† 'Roy. Soc. Proc.,' p. 379 *ante*.

assumed to be a linear function of the initial pressure  $P_0$ , it may be expressed by the formula

$$\alpha = 0.0036642 + 0.00000001457P_0,$$

where  $P_0$  is expressed in millimetres.

In the equation employed to calculate the temperature on the gas scale,\* the reciprocal of the coefficient corresponding to the pressure  $P_0$  replaces the corresponding values, 273.03 (or 273), for the ice point on the helium or hydrogen scales.

*Apparatus and method of experiment.*—The apparatus employed in these experiments was identical with that described by Travers, Senter, and Jaquero,† and employed by them in measuring the vapour pressure of liquid oxygen and liquid hydrogen on the constant volume hydrogen and helium scales. The volumes of the different parts of the apparatus were as follows :—

Volume of the bulb at 0° C. ....	24.264 c.c.
Volume of the stem.....	0.0625
Volume of the dead space .....	0.473

The method of experiment has already been fully described.‡

As the thermometer was a new one, it was thought advisable to fill it first of all with hydrogen, and to measure the vapour pressures of liquid oxygen on the hydrogen scale. The results, which were perfectly satisfactory, are as follows :—

#### Ice Point.

Pressure on gas .....	959.6 mm.
Temperature of dead space ...	16° 8 C.
Constant .....	86.863

The constant is the product of the pressure on the gas at the melting point of ice and the volume which the whole of the gas in the thermometer would occupy at that temperature, divided by the value of the temperature of the melting ice on the gas scale. The latter is the reciprocal of the pressure-coefficient for the gas corresponding to that particular pressure. Since the constant involves the three terms  $p$ ,  $v$ , and  $T$ , in the simple gas equation, a knowledge of it enables us to calculate temperatures, on the same scale, from observed pressures, when the volume is constant.

\* 'Phil. Trans.,' A, vol. 200, p. 145.

† 'Phil. Trans.,' A, vol. 200, p. 141.

‡ *Loc. cit.*

### Vapour Pressures of Liquid Oxygen on the Hydrogen Scale.

Pressure on gas in thermometer .....	286·55 mm.	286·65 mm.
Temperature of dead space .....	16°·5 C.	16°·6 C.
Temperature of stem .....	126°·0	126°·0
Vapour pressure of oxygen .....	235·4 mm.	236·5 mm.
Temperature—		
On new thermometer .....	80°·27	80°·30
From previous measurements .....	80°·26	80°·29

*Preparation of the oxygen.*—The oxygen employed was obtained by heating pure potassium permanganate contained in a glass tube, connected with the thermometer through a tube containing soda lime and a glass spiral, which could be immersed in liquid air; all the junctions were made by sealing together the various glass tubes in the blowpipe flame. The thermometer was first exhausted; oxygen was generated from the potassium permanganate, and allowed to liquefy in the glass spiral, and then to enter the thermometer. The latter was thoroughly washed out with the gas before it was finally filled.

### Vapour Pressures of Liquid Oxygen on the Constant-volume Oxygen Scale.

#### I.—Ice Point. December 10, 1902.

Pressure on gas .....	658·55 mm.
Temperature of dead space ..	15°·2 C.
Pressure coefficient .....	0·0036738
Constant .....	59·993

### Vapour Pressures of Liquid Oxygen.

#### December 12.

Pressure on gas in thermometer	203·7 mm.	204·6 mm.	205·3 mm.
Temperature of dead space .....	15°·9 C.	15°·7 C.	15°·2 C.
Temperature of stem .....	115°·5	124°·0	130°·0
Vapour pressure of oxygen .....	369·9 mm.	382·9 mm.	394·8 mm.
Temperature on oxygen scale ...	82°·62	83°·10	83°·37
Deviation from helium scale .....	1°·21	1°·02	1°·01

#### December 15.

Pressure on gas in thermometer	208·8 mm.	209·3 mm.	209·7 mm.
Temperature of dead space .....	17°·4 C.	17°·3 C.	17°·5 C.
Temperature of stem .....	110°·0	112°·0	113°·0
Vapour pressure of oxygen .....	477·8 mm.	488·1 mm.	498·2 mm.
Temperature on oxygen scale...	84°·88	85°·04	85°·15
Deviation from helium scale ...	1°·10	1°·14	1°·19

## II.—Ice Point. December 22, 1902.

Pressure on gas .....	483·8 mm.
Temperature of dead space ...	17°·9 C.
Pressure coefficient .....	0·0036713
Constant .....	43·993

## Vapour Pressures of Liquid Oxygen.

December 22.

Pressure on gas in thermometer.....	147·55 mm.	147·60 mm.
Temperature of dead space .....	18°·7 C.	18°·9 C.
Temperature of stem .....	125°·0	125°·0
Vapour pressure of oxygen .....	300·0 mm.	301·5 mm
Temperature on oxygen scale .....	81°·47	81°·47
Deviation from helium scale .....	0°·62	0°·72

December 29.

Pressure on gas in thermometer .....	146·12 mm.	146·52 mm.	147·22 mm.	148·42 mm.
Temperature of dead space .....	15°·4 C.	15°·4 C.	15°·9 C.	16°·1 C.
Temperature of stem .....	104°·0	104°·0	115°·0	130°·0
Vapour pressure of oxygen .....	283·6 mm.	291·4 mm.	297·1 mm.	332·2 mm.
Temperature on oxygen scale.....	80°·74	80°·95	81°·34	82°·00
Deviation from helium scale .....	1°·00	0°·99	0°·77	0°·99

## III.—Ice Point. January 2, 1903.

Pressure on gas .....	731 mm.
Temperature of dead space...	18°·1 C.
Pressure coefficient .....	0·0036748
Constant .....	66·524

## Vapour Pressures of Liquid Oxygen.

January 2, 1903.

Pressure on gas in thermometer	218·65 mm.	218·8 mm.	219·0 mm.
Temperature of dead space .....	18°·9 C.	18°·4 C.	18°·3 C.
Temperature of stem .....	92°·5	92°·5	92°·5
Vapour pressure of oxygen .....	260·0 mm.	262·5 mm.	265·0 mm.
Temperature on oxygen scale ...	79°·90	78°·96	80°·4
Deviation from helium scale ...	1°·18	1°·18	1°·18

## IV.—Ice Point. January 2, 1903.

Pressure on gas .....	336.0 mm.
Temperature of dead space .....	17° 0 C.
Pressure coefficient .....	0.0036692
Constant .....	30.538

## Vapour Pressures of Liquid Oxygen.

Pressure on gas in thermometer .....	109.3 mm.	109.4 mm.	109.7 mm.	109.85 mm.
Temperature of dead space .....	16° 8 C.	16° 7 C.	16° 7 C.	16° 7 C.
Temperature of stem .....	116° 0	116° 0	121° 0	121° 0
Vapour pressure of oxygen .....	591.8 mm.	591.8 mm.	614.1 mm.	618.5 mm.
Temperature on oxygen scale.....	87° 04	87° 14	87° 40	87° 50
Deviation from helium scale .....	0° 82	0° 72	0° 78	0° 78

*Discussion of the results.*—The mean values of the difference of the temperatures corresponding to the vapour pressure of liquid oxygen on the scales of the oxygen and helium thermometers, when plotted against the initial pressures at which the oxygen thermometer was filled, are found to lie nearly on a straight line. The smoothed results are as follows:—

Initial pressure.	$\Delta$ found.	$\Delta$ smoothed.
1000 mm.	—	1.5
731	1.18	1.18
658	1.11	1.11
484	0.85	0.89
336	0.77	0.72
0	—	0.4

The values at 1000 mm. and at zero pressure are obtained by extrapolation.

According to Callendar,\* the deviations of the constant volume helium and hydrogen thermometers from the thermo-dynamic scale should, at low temperatures, be equal and opposite in sign. According to this, the deviation of the boiling point of oxygen measured on the scale of an oxygen thermometer, filled at an initial pressure of 1000 mm., is 1° 4 below the true temperature, while the deviation in the case of the boiling point of hydrogen on the scale of a hydrogen thermometer is 0° 1, the thermometers being filled at an initial pressure of 1000 mm.

\* *Lac. cit.*

The deviation in the case of the hydrogen thermometer at the boiling point of that gas, supposing Callendar's results to be correct, appears relatively small, though the discrepancy is really due to the method of expressing the results, a degree at the lower temperature having a greater thermo-dynamic significance than at the higher temperature.

The fact that the value of the deviation does not vanish at zero pressure may possibly be due to a tendency of the gaseous molecules to associate. This tendency would be less affected by change of pressure than by change of temperature.\*

"On an Approximate Solution for the Bending of a Beam of Rectangular Cross-section under any System of Load.—Additional Note." By L. N. G. FILON, M.A., D.Sc. Communicated by Dr. C. CHREE, F.R.S. Received September 12, 1903.

My attention has lately been called by M. Flamant to certain discrepancies in some formulæ given by me in a paper recently published under the above title.†

On investigation I have found that a set of formulæ of the paper in question, namely, those of § 41, contained several inaccuracies.

I am unable to account for the introduction of these errors into the paper, and can only express my great regret that this mistake occurred and that I failed to detect it in time to remedy it before the paper was finally printed.

The most important of the final results, those relating to the stresses are, fortunately, correctly given.

The object of this short note is to give the results of § 41 of the paper referred to, in their amended form.

Equation (111) should read

$$\frac{B_1}{4} + D_1 + b^2 \left( -\frac{15B_3}{4} - 3D_3 \right) = 0$$

The equations following are correct, until we come to (128), which should be

$$B_3 = \frac{1}{3b^2} \left( D_1 + \frac{B_1}{4} \right),$$

$$D_3 = -\frac{1}{12b^2} \left( D_1 + \frac{B_1}{4} \right).$$

\* Ramsay, 'Phys. Soc. Proc.'

† 'Phil. Trans.,' A, vol. 201, pp. 63—155.